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Assessing longevity of ponderosa pine (Pinus ponderosa) snags in relation to age, diameter, wood density and pitch content

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Assessing longevity of ponderosa pine (*Pinus ponderosa*) snags in relation to age, diameter, wood density, and pitch content (46 pp.)

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Little is known about what factors contribute to the persistence of snags (standing dead trees) which are key elements of wildlife habitat in western forests. For this study, I investigated the relationships between tree age, diameter at breast height, wood density, and pitch content of ponderosa pine (*Pinus ponderosa*) snags and their longevity. Longevity was classified by whether the snag was standing or had broken off below 10 feet (3 m). I predicted that older snags and snags with greater pitch content would be more durable. Pitch content was not found to be higher in standing snags versus broken ones, but age was found to be significantly different. Snags standing 10 years after mortality by a wildfire event averaged 228±25 years at one site and 273±19 at another site, while those broken averaged 154±24 years and 182±23, respectively. The age versus longevity information gained from this study will help land managers in making decisions regarding snag habitat for wildlife. The testing for percent pitch content and outer wood density in relation to snag longevity was exploratory in nature and further study in these areas is needed to better understand how these factors relate to snag longevity.

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INTRODUCTION

Wildlife habitat is an important resource on national forest lands. More attention is now being paid to habitat for nongame species, yet little information is available on habitat needs for many of those species. Standing dead trees, or snags, are a key functional component of forests. An example of the significance of snags for wildlife is seen in the Blue Mountains of Oregon and Washington where 39 bird species and 23 mammal species were found to use snags to roost, nest, and/or feed (Thomas and others 1979). Scott and others (1977) noted that 85 species of primary- or secondary-cavity nesters in North America use snags. Harmon and others (1986) synthesized the literature to date on the importance of coarse woody debris, including snags, on forest structure and function. Snags are centers for biodiversity; they provide habitat for forest fungi, insects, insectivorous birds, cavity nesters and other animals (Harmon and others 1986, Patton 1988).

The importance of insectivorous birds on controlling insect epidemics was studied over 30 years ago (Bruns 1960, Franz 1961, Herberg 1965). Much of the early work done in Europe revealed that insectivorous birds do not single-handedly control insect outbreaks, but it was suggested that they may play an important role in helping to prevent outbreaks (Beebe 1974, DeGraaf 1977). In order to maintain high levels of biodiversity and to provide for a natural check on insect populations, large populations of various species of insectivorous birds are needed in our forests. Many species of insectivorous birds are dependent on snags for nesting and foraging sites (Thomas and others 1979). A lack of suitable snags is a major limiting factor for some bird species (Bruns 1960, Haapanen 1965, Balda 1975).

Ponderosa pine is one of the main snag species used by cavity-nesting birds in western Montana (McClelland and others 1979). Historically, ponderosa pine forests underwent frequent, low-intensity fires that kept the stands more open with larger pines (Arno 1980, Arno 1988, Wickman and Swetnam 1997). There is anecdotal evidence that young ponderosa pine trees fall quickly once they become snags, whereas old-growth ponderosa pine snags remain standing for a much longer time. It is hypothesized that historical fire regimes may have caused pitching of the trees, leading to more stout boles -- a sort of "case-hardening."

Conclusions drawn from previous studies on different tree species in various areas have indicated that larger snags tend to remain standing longer. Dahms (1949) studied ponderosa pine trees killed in a fire event in Oregon. He noted that the average diameter of the standing snags was 4 inches larger than those that had fallen 10 years post-fire. Keen (1955) studied beetle-killed ponderosa pine in southern Oregon and northern California and found the same relationship between size and longevity. Larger ponderosa pine snags were found to stand longer in Oregon (Bull 1983) and in Arizona (Scott 1978). The suitability of trees as nest sites was found to be related to a tree's age, and thus size (Conner 1978). Furthermore, Scott (1978) observed that the larger ponderosa pine snags had more woodpecker holes per snag. Cline and others (1980) found that Douglas-fir *(Pseudotsuga menziesii*) snag longevity was a function of diameter and age of the tree at the time of death. Following lodgepole pine (*Pinus contorta*) killed in a wildfire event, Lyon (1977) found that larger diameter snags stayed standing longer. It is postulated that since larger-diameter snags stay standing longer, they will be available for use by more species through time since some animals require hard snags while others need soft snags (Conner 1979, Thomas and others 1979, Mannan and others 1980, Neitro and others 1985).

The many bird species that utilize snags have various preferences such as tree species, minimum diameter, minimum snag height, and state and type of decay of the snag (Thomas and others 1979, Neitro and others 1985). Since the numerous bird species require an array of different snag attributes (size, state of decay, etc.) to meet their habitat needs, managers generally use a 'coarse scale' approach to snag management. They try to provide snag habitat for birds requiring the largest diameter and greatest density of snags (Conner 1979, Evans and Conner 1979, Neitro and others 1985) and assume that needs of other birds will be met. Snag management guidelines vary by National Forest in western Montana, but generally they specify preferred species (ponderosa pine and western larch, *Larix occidentalis*) and call for trees ≥20" (50.8 cm) in diameter showing signs of defect or decay (R. Hickle 1996, personal communication; M. Hillis 1996, personal communication; J. Ormiston 1996, personal communication; B. Summerfield 1996, personal communication).

Studies relating to pine extractives and decay resistance were begun early in this century (Humphry 1916, Hawley and others 1924, CSIRO 1958). Extractives, particularly from pines in the Southeast, are used in the naval stores industry and as tall oil precursors (Kurth 1952, Conner and others 1980) while the early work on decay resistance was important to the timber industry (Scheffer and Cowling 1966, U.S. Forest Products Laboratory 1967). While resistance of dead wood is still important to the timber industry, the benefits of coarse woody debris to the ecosystem are now more readily being recognized (Harmon and others 1986, Maser and Trappe 1984). Heartwood contains a greater amount of extractives than sapwood (Hillis 1977, Zavarin and Cool 1991). Extractives are also found in resin canals of *Pinus* species and in "woundwood" in greater quantities (Zavarin and Cool 1991). This wounding process is referred to as 'resinosis.' Toxicity to insects and diseases of some extractives (generally the terpenoids, flavenoids, tropolones, and stilbenes) found in the heartwood lead to increased decay resistance of the heartwood (Kurth 1952, Scheffer and Cowling 1966). Resistance is not consistent throughout the tree, however, with the most resistant region being in the outer heartwood near the base of the bole. Another major factor contributing to increased decay resistance is the higher lignin content formed when sapwood turns to heartwood (Scheffer and Cowling 1966). Regarding the work done on decay resistance and extractives, Harmon and others (1986) wrote, "...most ecological studies have failed to take wood extractives into account when comparing species and often seek to explain differences solely on the basis of Nitrogen content, size, or climate."

With these facts in mind, this study was initiated by the United States Forest Service, Intermountain Research Station (now Rocky Mountain Research Station) to investigate the relationships between ponderosa pine snags and their longevity in relation to the trees' fire history as live trees. The term 'pitch' used in this paper refers to the "waxes, fats, resins, phytosterol, and nonvolatile hydrocarbons" removed in the extraction process (ASTM 1984, TAPPI 1988).

OBJECTIVES

The overall purpose of this study was to gain a better understanding of factors affecting snag longevity in order for land managers to make more informed decisions concerning snag habitat. The process of resinosis that a coniferous tree undergoes when it is injured (Raffa and Berryman 1982, Owen and others 1987) is predicted to result in pitching of the bole, leading to a stronger, more persistent snag (Harrington 1996). Historically, such resinosis happened when pine trees were wounded by the naturally-occurring frequent, low intensity fires in Douglas-fir/ponderosa pine forests. Today, forest managers can use prescribed fire as a tool to mimic these historic fires.

The main objectives, then, were to examine the relationships between snag longevity and age, diameter, outer wood density, and pitch content. It was predicted that the snags that stand longer would be older and have a greater pitch content.

METHODS

STUDY SITES

Potential sites were identified according to stand history data obtained from the U.S. Forest Service and the Flathead Indian Reservation, Department of Forestry. The criteria used to select sites were similar habitat types (Pfister and others 1977), fire ecology groups (Fischer and Bradley 1987), aspect, year of stand-replacing fire event, no salvage logging following the fire, and the presence of numerous large-diameter [>15" (38.1 cm)] ponderosa pine snags to sample. Dissimilar site conditions, a lack of sufficient numbers of large snags, and salvage logging following fires greatly limited available study sites around western Montana and central Idaho.

Since a full-scale fire history study could not be conducted at each site, age of the tree at the time of death was substituted for fire history. The assumption was made that old-growth pines (trees >250 years old) had been exposed to frequent, non-lethal fires in their lifetimes; intermediate-aged pines (trees 100-250 years old) had been exposed to fire as young trees; and bull pines (trees <100 years old) had never survived low-intensity fires.

Due to time constraints, I could not follow individual snags through time so I sampled snags created in two fire event years--1988 and 1994. By selecting snags created in fire events from different years, I could assess longevity over time. The two sites that burned in 1988 were Petty Creek 1 and 2, located on the Lolo National Forest about 30 miles west of Missoula, Montana. The two sites that burned in 1994 were Magruder, located in the Selway-Bitterroot Wilderness in central Idaho; and Niarada, located north of Polson, Montana on the Flathead Indian Reservation. All the sites had some old-growth trees with numerous old fire scars visible indicating that the sites had undergone non-lethal underburns historically.

The fire that burned the Petty Creek area was a human-caused fire in July 1988 and was essentially a stand-replacing burn, meaning that virtually no trees survived the fire. Petty Creek 1 was owned by a private timber company prior to the burn, but has subsequently been acquired by the U.S. Forest Service. Because of this recent change in ownership, no stand history could be obtained; however, there was no evidence of logging prior to or following the fire. Petty Creek 2, located about one air-mile west of Petty Creek 1, is owned by the U.S. Forest Service and was not harvested prior to or following the fire.

Magruder, located in the Selway-Bitterroot Wilderness area, was not affected by logging prior to or following the 1994 fire. It appeared that the fire at Magruder was more patchy and less intense than the one at Petty Creek, resulting in more trees surviving. I would classify this as a mixed-severity burn.

Niarada is located on the Flathead Indian Reservation and there was no evidence of logging either prior to or following the 1994 burn. Like Magruder, it seemed the fire at Niarada was less intense than at Petty Creek, leaving more surviving trees. There was one Douglas-fir (*Pseudotsuga menziesii*) near the road with old fire scars on it. The tree had been cut and removed by firewood gatherers following the fire so I was able to take a cross-section from the stump. The tree originated in 1861 and had a definite fire scar around 1889 with probable fire scars from 1898 and 1912. The mean fire interval for the period before 1912 was 17 years, with no evidence of a fire since that time. This cross-section is evidence that this area experienced frequent, non-lethal fires prior to the early part of this century.

Table 1 shows a summary of the site characteristics of the four sites sampled, including aspect, slope, elevation, habitat type (Pfister and others 1977), fire ecology group (Fischer and Bradley 1987) and the years in which each stand burned.

Table 1. Aspect, slope, elevation, habitat type, fire ecology group, and the year each stand burned for each of the four study sites.

Site	Aspect	Slope	Elevation (feet/meters)	Habitat type[1]	Fire ecology group[2]	Year burned
Petty Creek 1	W	51%	4000 / 1219	PSME/CARU-PIPO	4	1988
Petty Creek 2	S-SW	42%	4200 / 1280	PSME/FESC	4	1988
Niarada	W	33%	4700 / 1433	PSME/CARU-PIPO	4	1994
Magruder	W-NW	63%	4100 / 1250	PSME/SYAL-CARU	6	1994

[1]Pfister and others (1977)
[2]Fischer and Bradley (1987)

The habitat types listed in table 1 did not necessarily coincide with those attained from records of examination taken prior to the fires. At all sites except Niarada, habitat typing in the field was difficult due to an overwhelming invasion of knapweed (*Centaurea maculosa*) at the sites.

Table 2 shows the total number of snags sampled at each site by age class with the number of those that were broken.

Table 2. Total number of snags sampled at each site as well as the number of those that were broken.

	total # snags sampled by age class (# broken)		
Site	Bull	Intermediate	Old-growth
Petty Creek 1	4 (3)	20 (11)	7 (2)
Petty Creek 2	1 (1)	11 (6)	10 (2)
Niarada	1 (0)	20 (1)	2 (0)
Magruder	7 (0)	10 (0)	10 (0)

FIELD

Initially, I intended to age each snag >15" (38.1 cm) diameter at breast height (dbh) at each site and then sub-sample in order to obtain a good representation of each age class for both standing and broken snags. I quickly found that this was not realistic in terms of time and effectiveness. Generally, there was a lack of bull pines and it became apparent that there was not a good representation across age classes for the standing and broken trees. So, at each location, every snag that was available was sampled. A few snags could not be sampled due to safety concerns, inadequate bore length, I thought the snag died because of factors other than as a direct result of the fire (e.g., insect attack following the fire), or the bole of the tree had burned through and the sampling area was missing from the tree.

At each snag, site characteristics such as habitat type, aspect, slope, and location via global positioning system (GPS) were recorded. Tree data recorded included diameter at breast height, whether the snag was broken off below 10 feet (3 m), and height of the snag. I also noted feeding or nesting cavities of birds, fire scars, and presence of rot in the bole of the tree (Appendix I).

At least one core was taken to determine the age of each tree. If necessary, boring was repeated until an acceptable core was obtained. These cores were taken as close to ground-line as possible and were glued into grooved core boards and marked according to snag number and bore height for laboratory analysis. Cores were also taken to assess fire scar dates, when possible.

Wood density

Three core samples from the outer 10 cm of the snag were taken for wood density measurements. In order to determine where on the tree a sample should be taken, a random number generator was used. The number generated was between 0 and 360 and used as the azimuthal direction from the center of the tree where a core was then taken. Cores were taken at approximately 2.5 (76 cm) feet above ground level so that the density measure was taken at the same general height as the cores for pitch. The increment borer was marked at 10 cm and inserted into the tree to that point, giving consistent sampling volume for density calculations. Each of the three density cores were placed in individual plastic, zip-locked sandwich bags, which were sealed and marked.

Pitch content

Several increment cores were taken at approximately 3 feet (91 cm) above ground level on the two sidehill portions of each tree (not the uphill or downhill sides) to be used for pitch analysis. All the cores from a given tree were placed in one plastic, zip-locked sandwich bag, which was sealed and labeled. The number of cores taken from each snag was determined by estimating when sufficient sample weight (~10 g) had been gathered for the chemical analysis. For consistency, an even number of cores was taken from each tree, with the same number taken from each side. The number of cores taken per tree was usually four, six, or eight. It took two people about six weeks to complete field sampling.

LABORATORY

Age data

The field-mounted cores were sanded using an orbital sander with sandpaper grit up to 120 grains. Fragile cores were sanded by hand. Tree rings were counted under a dissecting scope or with a hand lens. If the pith of the tree was not intersected, a set of concentric circles was positioned over the core to estimate approximately how many rings were missed (Ghent 1955). For instance, if there were 2 rings per mm and it was estimated to be 3 mm to the pith, the correction added would be 6 years. Also added into the ring count was an adjustment for the height at which the core was taken (Arno and others 1985, Fiedler 1984). The total age of the tree was computed according to the following equation:

Total age of tree = A + P + H

where:

A = Actual count,

P = Estimated years to pith, and

H = Estimated years to height of core extraction.

Additional corrections were added to some cores that had substantial rot. First, I assigned each of the cores a rating for quality--either good, minimal rot, or rot. To the 'good' cores I added zero years; to the cores with 'minimal rot' I added 30 years; and to the cores with 'rot,' I added 80 years. I arrived at these corrections by estimating how much of the core was missing and by looking at other cores from the sites to determine the average number of years I lost to rot. I feel that these additions added to the accuracy of the ages, yet were still conservative. The trees were then assigned to an age class. Bull pine are those <100 years old, intermediate pine are those 100-250 years old, and old-growth pine are those >250 years old.

Wood density

Since many of the density samples were little more than dust, the samples were not removed from the zip-locked sandwich bags. The same brand of bags was used and 25 empty bags were weighed and dried in the same manner as the bags containing wood density samples to determine the average weight of the bags, along with the variability among the bag weight. This was also done in order to ensure that none of the weight loss was from the bag. The zip-locked bags containing the cores for density analysis were weighed and then placed open in a drying oven at 50°C for 24 hours. They were then weighed again to determine the dry mass of each sample. The average weight of the empty bags was subtracted to obtain the dry weight of the sample alone.

The following equations were used:

Volume of core sample = $\pi r^2 h = \pi\ (0.25\ \text{cm})^2 \times 10\ \text{cm} = 1.96\ \text{cm}^3$

Dry weight of sample (g) = [Dry weight of sample + bag (g)] - Average dry weight of empty bags (g)

Density = Dry weight of sample (g) / 1.96 cm^3 = g/cm^3

Chemical analysis for pitch content

Core samples were processed to a granular size dictated by the analytical procedures I followed (ASTM 1984, TAPPI 1988). The core samples were broken into small pieces and then ground in a small Wiley© mill. The ground matter was sifted and the material that could pass through a number 40 mesh screen, but not through a number 60 mesh screen was set aside. Bits that were still too large were then re-ground and the process was repeated until all the wood was successfully ground.

The standard testing methods (ASTM 1984) call for analyzing and drying two separate wood samples. Since I had a limited amount of material to work with, I lowered the drying temperature, increased the drying time, and used the same sample for both moisture determination and pitch content analysis. Approximately 2 g of ground wood were placed in a tared Alundum thimble, which was then placed in a stoppered glass weighing bottle. The entire assembly was weighed three times and then placed (unstoppered) in a drying oven at 50°C for a 24-hour period. After drying, the stopper was placed on the weighing bottle and the whole assembly was placed in a desiccator to be cooled. Three weighings were then taken to determine the dry weight of the sample. Moisture content, in percent moisture of dry weight, was determined using the average of the three wet measures and the average of the three dry weights (Appendix III).

The dried and weighed sample was then placed in a Soxhlet extraction apparatus with 150 ml of dichloromethane (also known as methylene chloride or DCM) in the flask. Dichloromethane is used to extract "waxes, fats, resins, phytosterol, and nonvolatile hydrocarbons" (ASTM 1984, TAPPI 1988). The Soxhlet devices were located in a fume hood due to the potentially toxic effects of DCM. The sample was allowed to be extracted for a period of two hours with at least 6 siphonings per hour (ASTM 1984, TAPPI 1988). After the run was completed, the DCM solution with the extractives was transferred to a tared 100 ml beaker. The DCM was evaporated until only 20-25 ml was remaining. Next, the beaker was placed in an oven at 105°C for a 1-hour period. The beakers were cooled in a desiccator and then re-weighed to determine gain. The pitch content is reported as percent of the dry weight of the sample, before extraction.

The standard methods (ASTM 1984, TAPPI 1988) call for an extraction time of five hours, but after several test runs in a preliminary study, it was determined that there was no difference in percent of extracted amount after two hours versus five hours. Duplicate analysis was conducted for each snag sample in order to get an idea of the reliability of the test and the variability of the pitch content within each ground sample.

After each analysis, the Alundum thimbles were cleaned in a Thermolyne© oven at 500°C for three hours. It took approximately 15 hours for the thimbles to cool back to room temperature before they could be used again.

With 206 analyses to run (103 snags x 2 runs each), this was by far the most time-consuming portion of this study. On average, less than one snag sample was ground in the Wiley© mill per day. In addition to the actual number of days required for the chemical analysis, there were about 1.5 days of 'down-time' between runs before the thimbles could be used due to the cleaning time and the drying time for the next samples. Out of a 7-day week, a maximum of five could be chemical analysis days. I had 3 Soxhlet extraction set-ups and chemical analysis took about 8 months to complete.

Statistical Analysis

I conducted goodness-of-fit tests using the G-test (Sokal and Rohl 1981) on the Petty Creek 1 data with the categorical variables 'age class' versus 'broken.' I was unable to conduct this test on the other three sites as there were zeros in one or more of the cells. I also ran the G-test on the combined data for Petty Creek 1 and 2.

Other data analysis was accomplished primarily on the computer using JMP IN® Software (SAS 1996). Two-sample t-test or analysis of variance tests were conducted for categorical measures versus continuous measures (e.g., 'age class' versus 'dbh'), as well as Wilcoxon rank sum test or Kruskal-Wallis tests where there was concern that the data may not behave normally. If a significance was indicated and there were more than two categories, Tukey-Kramer HSD was run to determine where the significance was located. Regression analysis was conducted on continuous versus continuous measures (e.g., 'average density' versus 'average pitch'). All significance tests were conducted at α = 0.05.

RESULTS

The sample data distribution were relatively normal for age, dbh, average pitch, and average wood density (see Appendix III for distribution data), especially considering the small sample sizes. Based on the assumption that the population data for these attributes was normally distributed, I accepted the parametric results with one exception. That one exception was because the nonparametric and parametric results differed in their outcome and practical significance was evident only with the nonparametric test results.

Tables 3-6 show the mean and standard error of the sample mean for each of the attributes (age, dbh, average pitch, and average density) at each location by age class and snag status (all, standing, broken). Statistical differences are also indicated and will be discussed on a site by site basis.

Table 3. Mean and standard error of the sample mean for age (years) for each study site (Petty Creek 1, Petty Creek 2, Niarada, and Magruder) for each age class (bull pine, intermediate pine, and old-growth pine) according to snag condition (all, standing, or broken).

		all	n	standing	n	broken	n
Bull pine	Petty Creek 1	83±5	4	74	1	85±6	3
	Petty Creek 2	63	1	--	0	63	1
	Niarada	66	1	66	1	--	0
	Magruder	93±1	7	93±1	7	--	0
Intermediate pine	Petty Creek 1	156±10	20	171±14	9	143±13	11
	Petty Creek 2	189±15	11	**221±11 (a)**	5	**163±21 (a)**	6
	Niarada	193±8	20	194±8	19	168	1
	Magruder	225±9	10	225±9	10	--	0
Old-growth pine	Petty Creek 1	349±28	7	361±38	5	317±16	2
	Petty Creek 2	305±11	10	306±12	8	299±36	2
	Niarada	341±38	2	341±38	2	--	0
	Magruder	320±18	10	320±18	10	--	0

a: $t=2.366$, $P=0.042$

Table 4. Mean and standard error of the sample mean for diameter at breast height (inches) at each site (Petty Creek 1, Petty Creek 2, Niarada, and Magruder) for each age class (bull pine, intermediate pine, and old-growth pine) according to snag condition (all, standing, or broken).

		all	n	standing	n	broken	n
Bull pine	Petty Creek 1	**15.3±0.6 (a)**	4	16.9	1	14.8±0.42	3
	Petty Creek 2	15	1	--	0	15	1
	Niarada	17.3	1	17.3	1	--	0
	Magruder	**18.1±0.6 (c, d)**	7	18.1±0.6	7	--	0
Intermediate pine	Petty Creek 1	**18.5±0.6 (b)**	20	18.7±1.1	9	18.3±0.8	11
	Petty Creek 2	22.3±1.1	11	24.3±1.7	5	20.6±0.9	6
	Niarada	20.6±0.8	20	20.7±0.8	19	18.4	1
	Magruder	**26.5±1.4 (c)**	10	26.5±1.4	10	--	0
Old-growth pine	Petty Creek 1	**22.9±1.4 (a, b)**	7	24.1±1.6	5	19.7±0.60	2
	Petty Creek 2	19.7±1.0	10	19.8±1.3	8	19.7±1.3	2
	Niarada	29.7±5.6	2	29.7±5.6	2	--	0
	Magruder	**28.5±1.7 (d)**	10	28.5±1.7	10	--	0

a: t= -3.021, P=0.004
b: t= -3.258, P=0.003
c: t= -4.707, P<0.001
d: t= -5.061, P<0.001

Table 5. Mean and standard error of the sample mean for average pitch (% of dry weight) at each site (Petty Creek 1, Petty Creek 2, Niarada, and Magruder) for each age class (bull pine, intermediate pine, and old-growth pine) according to snag condition (all, standing, or broken).

		all	n	standing	n	broken	n
Bull pine	Petty Creek 1	6.78±1.36	4	7.82	1	6.44±1.86	3
	Petty Creek 2	16.16	1	--	0	16.16	1
	Niarada	4.80	1	4.80	1	--	0
	Magruder	8.23±2.07	7	8.23±2.07	7	--	0
Intermediate pine	Petty Creek 1	12.61±1.43	20	12.15±2.02	9	12.98±2.10	11
	Petty Creek 2	10.87±1.25	11	8.83±1.96	5	12.57±1.39	6
	Niarada	7.14±0.88	20	7.02±0.92	19	9.53	1
	Magruder	9.07±1.59	10	9.07±1.59	10	--	0
Old-growth pine	Petty Creek 1	13.48±2.31	7	13.61±2.12	5	13.15±8.20	2
	Petty Creek 2	7.56±1.23	10	7.11±1.24	8	9.33±4.61	2
	Niarada	6.56±2.49	2	6.56±2.49	2	--	0
	Magruder	5.10±0.68	10	5.10±0.68	10	--	0

Table 6. Mean and standard error of the sample mean for average density (g/cm^3) at each site (Petty Creek 1, Petty Creek 2, Niarada, and Magruder) for each age class (bull pine, intermediate pine, and old-growth pine) according to snag condition (all, standing, or broken).

		all	n	standing	n	broken	n
Bull pine	Petty Creek 1	0.30±0.10	4	0.51	1	0.23±0.10	3
	Petty Creek 2	0.24	1	--	0	0.24	1
	Niarada	0.54	1	0.54	1	--	0
	Magruder	0.46±0.02	7	0.46±0.02	7	--	0
Intermediate pine	Petty Creek 1	**0.25±0.03 (a)**	20	**0.32±0.05 (b)**	9	**0.19±0.03 (b)**	11
	Petty Creek 2	**0.18±0.02 (c)**	11	0.18±0.04	5	0.18±0.02	6
	Niarada	0.40±0.02	20	0.40±0.02	19	0.36	1
	Magruder	0.49±0.02	10	0.49±0.02	10	--	0
Old-growth pine	Petty Creek 1	**0.47±0.03 (a)**	7	0.48±0.04	5	0.47±0.04	2
	Petty Creek 2	**0.35±0.04 (c)**	10	0.35±0.05	8	0.35±0.14	2
	Niarada	0.53±0.04	2	0.53±0.04	2	--	0
	Magruder	0.45±0.03	10	0.45±0.03	10	--	0

a: $t= -4.017$, $P<0.001$
b: $t=2.471$, P0.024
c: $t= -3.808$, $P=0.001$

In order to succinctly report all relationships for longevity (standing versus broken), diameter distribution, age class, pitch content, and density for each site, the data are presented in separate tables for each study site with statistical values shown (tables 7-10). Also, I show if and how those relationships change when the data from each fire year are grouped together (tables 11-12).

A note of caution is needed regarding the wood density relationships. There were obvious differences in the wood densities for trees that had broken below 10 feet (3 m) versus those still standing, but the broken boles had been exposed to different weathering than the intact boles at the point where the cores were extracted. The differences in wood density could be a result of the breaking, not vice versa.

Petty Creek 1 (tables 3-7)

The G-test for goodness-of-fit conducted for Petty Creek 1 (PC1) suggested that age class and longevity were not related ($P>0.250$). A note of caution is required, though, as some of the cell populations were small.

Petty Creek 1 data revealed there were significant relationships between snag longevity and age ($P=0.042$). The actual ages were used instead of the age classes for this test. It was found that the mean age of broken snags ($n=16$) was 154±24 years while the mean age of those still standing ($n=15$) was 228±25 years.

Without separating the data by age class, the broken snags were significantly less dense than those standing. Standing snags had a mean density of 0.39±0.04 g/cm^3 and broken ones averaging 0.23±0.03 g/cm^3 ($P=0.004$). After grouping the data according to age classes, there were two more significant findings. There was a difference between average density of intermediate pines (0.25±0.03) and old-growth pines (0.47±0.03) ($P=0.004$). There was also a significant difference between the standing and broken pines in the intermediate age class ($P=0.024$), with the standing being more dense (0.32±0.05) than the broken (0.19±0.03).

As would be expected, older trees were also larger in diameter. The ANOVA determined that there were significant differences ($P=0.0007$) and Tukey-Kramer HSD indicated that the only significant difference was that old-growth trees were larger (22.9±1.1") than both intermediate-aged and bull pines. Although the mean of the intermediate age class was about three inches greater than that of the bull pine class (18.5±0.7" versus 15.3±1.5"), it was not a significant difference.

Table 7. Summary of correlation analyses for longevity, dbh, age class, average pitch, and average density for Petty Creek 1, n=31. Significant results are in bold (P<0.05).

	dbh	Age class	Average pitch	Average density
Longevity	t-test t=2.030, P=0.052	**t-test t=2.126, P=0.042 (actual ages used)**	t-test t=0.252, P=0.803	**t-test t=3.132, P=0.004**
dbh	---	**ANOVA F=9.517, P=0.0007**	t-test t=0.33, P=0.745	t-test t=1.15, P=0.261
Age class	---	---	ANOVA F=1.790, P=0.186	**ANOVA F=6.959, P=0.004**
Average pitch	---	---	---	t-test t= -0.76, P=0.455

Petty Creek 2 (tables 3-6, 8)

As with PC1, broken snags at Petty Creek 2 (PC2) were significantly younger (P=0.005). Mean age of standing snags (n=13) was 273±19 years and mean age of broken ones (n=9) was 182±23 years. When grouped into age classes, there was a significance seen in age between standing and broken snags of the intermediate age class (P=0.042) with broken snags averaging 163±21 years and standing snags averaging 221±11 years.

The average pitch for all broken snags (12.25±1.30%) was significantly higher than that for standing snags (7.77±1.08%) (P=0.015). There was a significant negative relationship between dbh and average density (P=0.03). Consistent with PC1, old-growth trees were more dense (0.35±0.04 g/cm^3) than intermediate-aged pines (0.18±0.02 g/cm^3) (P=0.005).

Table 8. Summary of correlation analyses for longevity, dbh, age class, average pitch, and average density for Petty Creek 2, n=22. Significant results are in bold (P<0.05).

	dbh	Age class	Average pitch	Average density
Longevity	t-test t=1.123, P=0.275	**t-test t=3.119, P=0.005 (actual ages used)**	**t-test t= -2.649, P=0.015**	t-test t=1.080, P=0.293
dbh	---	ANOVA F=3.022, P=0.073	t-test t= -0.66, P=0.514	**t-test t= -2.34, P=0.03**
Age class	---	---	ANOVA F=3.159, P=0.065	**ANOVA F=7.266, P=0.005**
Average pitch	---	---	---	t-test t= -1.11, P=0.279

Niarada (tables 3-6, 9)

Since there was only one broken snag at Niarada, I was unable to study longevity there. There were no significant relationships found with the Niarada data.

Table 9. Summary of correlation analyses for between longevity, dbh, age class, average pitch, and average density for Niarada, n=23. Significant results are in bold (P<0.05).

	dbh	Age class	Average pitch	Average density
Longevity (only one broken tree)	ANOVA F=0.419, P=0.525	ANOVA F=0.269, P=0.61	ANOVA F=0.465, P=0.503	ANOVA F=0.310, P=0.583
dbh	---	Kruskal-Wallis χ^2=3.945, P=0.139	t-test t=1.28, P=0.216	t-test t=1.43, P=0.166
Age class	---	---	ANOVA F=0.185, P=0.833	ANOVA F=2.754, P=0.088
Average pitch	---	---	---	t-test t= -0.49, P=0.631

Magruder (tables 3-6, 10)

As with Niarada, there was no capacity to analyze longevity at Magruder because there were no broken snags sampled at Magruder. The only significance found at Magruder was with age class versus dbh (P<0.001). Intermediate and old-growth pines were each significantly larger than bull pines. The mean diameter for old-growth pines was 28.5±1.4," for intermediate-aged pines it was 26.5±1.4," and for bull pines it was 18.1±1.6."

Table 10. Summary of correlation analyses for longevity, dbh, age class, average pitch, and average density for Magruder, n=27. Significant results are in bold (P<0.05).

	dbh	Age class	Average pitch	Average density
Longevity (No broken trees)	---	---	---	---
dbh	---	**ANOVA F=12.962, P<0.001**	t-test t= -0.39, P=0.698	t-test t= -1.55, P=0.134
Age class	---	---	ANOVA F=2.299, P=0.122	ANOVA F=0.636, P=0.538
Average pitch	---	---	---	t-test t= -1.39, P=0.176

Combined sites

The distribution of the variables dbh, age, average pitch, and average density was relatively normal for all sites (Appendix III). For PC1 and PC2, there were no significant differences seen in mean dbh, age, average pitch, or average density (figs. 1-4). For Magruder and Niarada, there was only one significant difference-- mean dbh (25.1±0.9" versus 21.3±1.0"). Based on these findings, I felt it was appropriate to combine the data

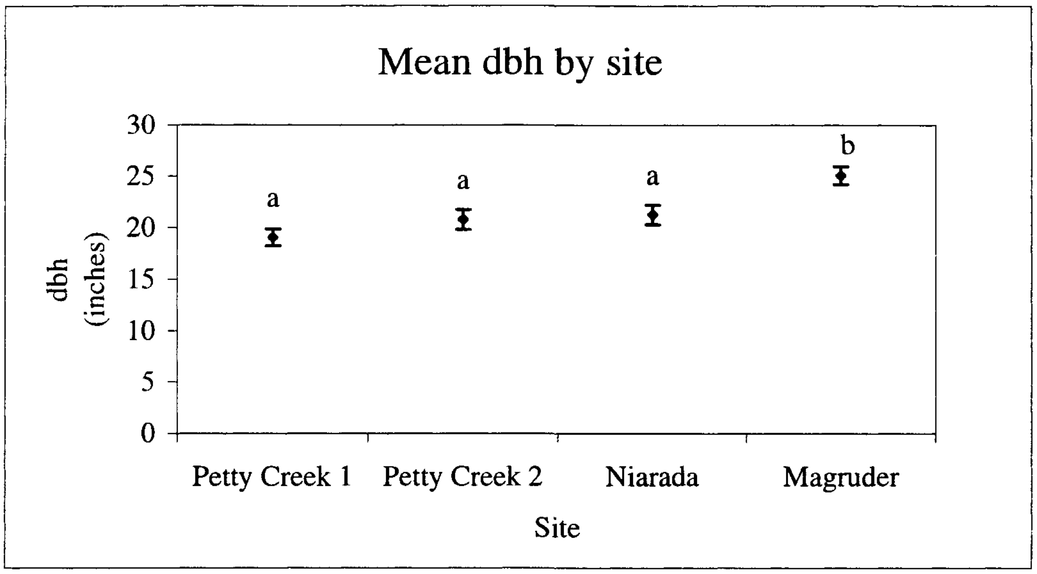

Figure 1. Mean diameters (inches) and standard errors of the sampling means by site. Statistically different means are indicated with different letters (P<0.05).

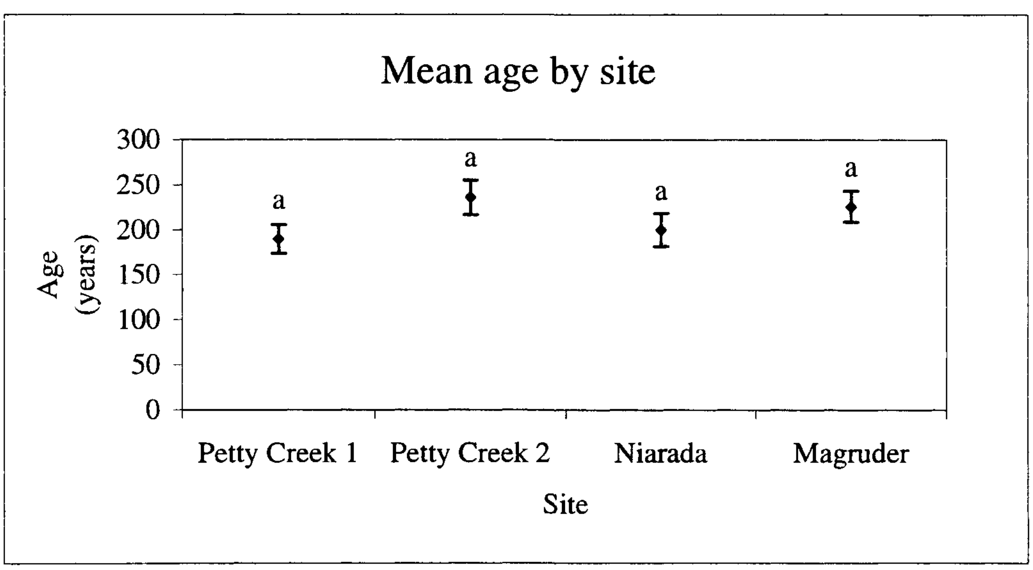

Figure 2. Mean ages (years) and standard errors of the sampling means by site. Statistically different means are indicated with different letters (P<0.05).

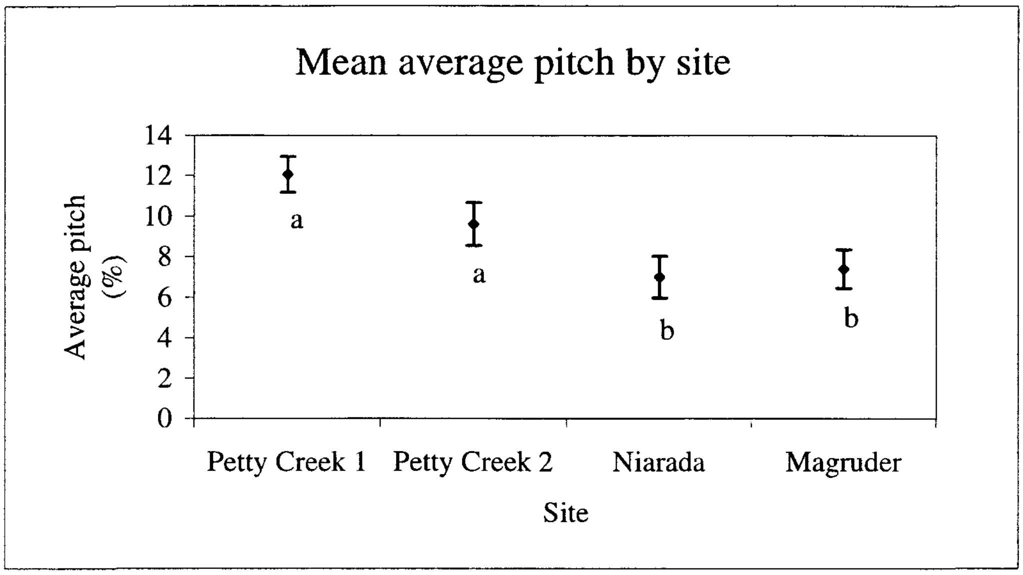

Figure 3. Mean average pitch (%) and standard errors of the sampling means by site. Statistically different means are indicated with different letters (P<0.05).

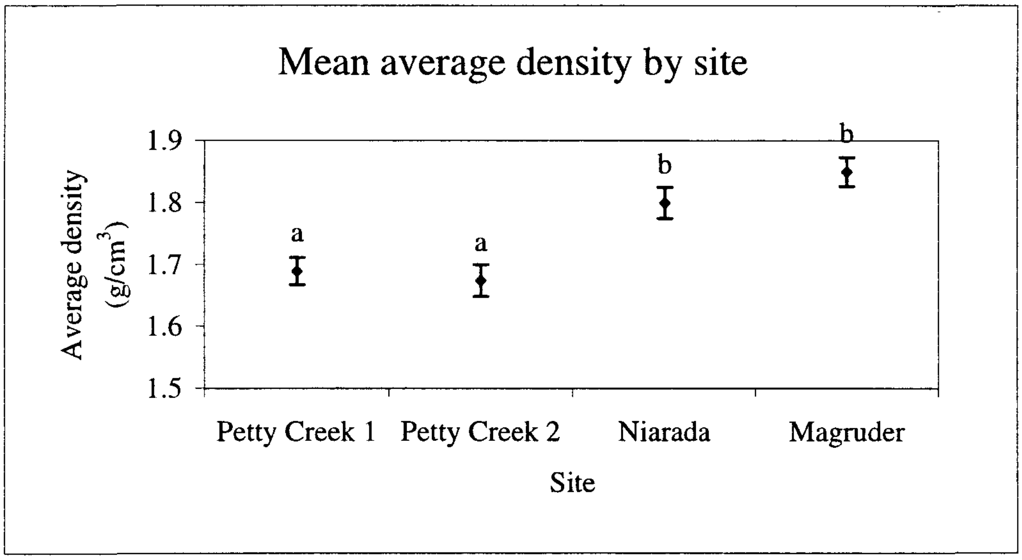

Figure 4. Mean average density (g/cm^3) and standard errors of the sampling means by site. Statistically different means are indicated with different letters (P<0.05).

from the two 1988 sites together and the data from the two 1994 sites together to investigate the influences of larger sample sizes on the relationships.

1988 Sites (table 11)

The G-test for goodness-of-fit was conducted on the combined PC1 and PC2 data for age class versus longevity. The test indicated that age class and longevity were related ($P=0.001$).

For the other statistical measures on the combined data from PC1 and PC2, five significant relationships were seen. The first, dbh versus longevity, was not detected in either individual site ($P=0.019$). Broken snags had a significantly smaller diameter than non-broken ones (18.5±0.7" versus 20.9±0.7").

As was seen in both individual sites, broken snags were significantly younger than non-broken snags ($P<0.001$) with a mean age of 164±17 years. The standing snags averaged 249±16 years old. One more significance was seen with regards to longevity; broken snags were significantly less dense ($P=0.0049$) than standing snags (0.23 ± 0.03 g/cm^3 versus 0.34 ± 0.03 g/cm^3).

The diameter distribution for the three age classes showed successively larger means. The ANOVA held significance with $P=0.008$, but the only significance was that the mean of bull pines was smaller than the mean for either intermediate pines or old-growth pines (according to the Tukey-Kramer HSD). Old-growth pines averaged 21.1±0.8," intermediate pines averaged 19.8±0.6," and bull pines were 15.3±0.8" in diameter.

The final test of significance was that old-growth trees were significantly more dense than the intermediate-aged trees ($P=0.0002$ and Tukey-Kramer HSD). Average density for the bull pines was quite variable, leading to a mean of 0.29±0.06 g/cm^3, causing it to overlap both intermediate and old-growth pine distributions. Intermediates averaged 0.23±0.02 g/cm^3, while old-growth trees averaged 0.40±0.03 g/cm^3.

Table 11. Summary of correlation analyses for longevity, dbh, age class, average pitch, and average density for 1988 sites combined, n=53. Significant results are in bold (P<0.05).

	dbh	Age class	Average pitch	Average density
Longevity	**t-test t=2.433, P=0.019**	**t-test t=3.566, P<0.001 (actual ages used)**	t-test t= -1.115, P=0.27	**t-test t=2.943, P=0.005**
dbh	---	**ANOVA F=5.365, P=0.008**	t test t= -.041, P=0.681	t-test t= -0.50, P=0.621
Age class	---	---	ANOVA F=1.922, P=0.312	**ANOVA F=10.472, P=0.0002**
Average pitch	---	---	---	t-test t= -0.93, P=0.355

1994 Sites (table 12)

Combining Magruder and Niarada did little to increase the number of relationships found to be significant. The one relationship found to be significant was age class versus dbh (P<0.001). In the combined sites, however, all age classes were significantly different from one another. The old-growth trees averaged 28.7±1.3," mean for the intermediate-aged trees was 22.6±0.8," and the average for the bull pines was 18.0±1.6."

Table 12. Summary of correlation analyses for longevity, dbh, age class, average pitch, and average density for 1994 sites combined, n=50. Significant results are in bold (P<0.05).

	dbh	Age class	Average pitch	Average density
Longevity (Only one broken snag)	t-test t=0.887, P=0.38	t-test t=0.553, P=0.583 (actual ages used)	t-test t= -0.562, P=0.577	t-test t=0.950, P=0.347
dbh	---	**ANOVA F=14.641, P<0.001**	t-test t=0.39, P=0.702	t-test t=0.63, P=0.535
Age class	---	---	ANOVA F=1.620, P=0.209	ANOVA F=1.183, P=0.315
Average pitch	---	---	---	t-test t= -1.11, P=0.274

As a final summary of the results obtained from the individual sites or combined sites, table 12 presents the relationships and which sites had significant results among them.

Table 13. Summary table of which sites showed significant results (P<0.05) in correlation analyses for longevity, dbh, age class, average pitch, and average density.

	dbh	Age class	Average pitch	Average density
Longevity	1988	PC1, PC2, 1988	PC2	PC1, 1988
dbh	---	PC1, 1988, Magruder, 1994	---	PC2
Age class	---	---	---	PC1, PC2, 1988
Average pitch	---	---	---	---

Even though I made no direct comparisons between different years, some interesting differences were seen. There was no difference between mean age of the 1994 sites (214±13 years) and 1988 sites (209±12 years) (fig. 5), but the snags making up the 1994 sites were significantly larger (fig. 6). The mean diameter of snags from the 1994 sites was 23.3±0.7" and the mean from 1988 sites was 19.8±0.7." This difference could be attributed to different site conditions and thus growing conditions, or it could be due to more bark remaining on the 1994 snags.

Average density was significantly higher for the 1994 sites (fig. 7). The mean was 0.49±0.02 g/cm^3 compared to 0.29±0.02 g/cm^3 for the 1988 sites ($P<0.0001$). Counter to this, the average percent pitch was significantly higher for the snags from the 1988 sites (fig. 8). The mean was 11.04±0.68% compared to only 7.20±0.71% for the 1994 sites ($P<0.0001$).

MANAGEMENT IMPLICATIONS

The pitch extraction methods I used were reliable, showing very little variation between the two separate tests run on each snag sample. The predication that pitch would be higher in the old-growth trees was not born out by this study; however, I do not think the picture is clear. Since I combined sapwood and heartwood together for the chemical analysis, outcomes were likely affected. Heartwood generally has more pitch in it (Conner and others 1980) and, depending on the proportion of heartwood to sapwood, the overall percent pitch will be affected (Scheffer and Cowling 1966). Also at play here is the density of the outer wood. With increasing rot in the outer sapwood area, the percent pitch would presumably increase as the proportion of heartwood in the sample would be much greater. This could explain the general opposition of percent pitch and density measure as seen at PC2, Magruder, and to some degree at Niarada as well as in the combined 1994 and 1988 data. Future studies of this type should separate the heartwood from the sapwood in the field and conduct the chemical analysis on them separately.

The minimum diameter guidelines for ponderosa pine snag recruitment in western

Montana are generally about 20". My data indicates that this should be raised a few inches, providing a more conservative parameter (Conner 1979). The differences in snag diameter between broken and standing snags was not significant at either PC1 or PC2. At PC1, broken snags averaged 17.8" while those still standing averaged 20.4" (P=0.0516). At PC2, the difference was even less with broken snags averaging 19.7" and standing snags averaging 21.5" (P=0.2748).

Age, density, and longevity showed some interesting interactions on the 1988 sites. The old-growth trees were significantly more dense, and snags that had broken off were significantly younger and less dense than those still standing. I think this is where the most crucial management implications lie. According to the data I collected, ponderosa pine snags in western Montana have a greater chance of remaining standing at least 10 years if the trees are >250 years old.

I think that age should be added to the management guidelines as a criterion as it appears that older trees stay standing longer once they die. It is important to keep in mind that the ponderosa pine trees that were >250 years old in 1988 experienced a very different environment than trees currently do. The primary difference is that Douglas-fir/ponderosa pine forests lack the frequent, non-lethal underburns which historically helped to maintain more open sites. That fire regime helped to recycle nutrients and reduced competition stress to the remaining trees, thus presumably increasing tree vigor.

Further studies are needed to provide more precise snag guidelines for managers, both in the Northern Rocky Mountains and elsewhere. Proposals to 'restore' ponderosa pine forests to pre-European settlement structure and composition with thinning and reintroduction of fire will need to carefully consider how these treatments may affect both standing and potential snags. This fact is underscored by this study, in particular, since the most persistent snags appear to be in the relatively rare old-growth snags. There were few old-growth pines at my sites. If this is indicative of the overall age composition of pine forests in the Northern Rocky Mountains, silvicultural tools such as shelterwood harvesting and prescribed fire need to be used wisely in order to retain both potential old-growth snags and a good seed-source for future ponderosa pine forests. Even more noteworthy was the relative lack of bull pines at my study sites, which indicates that recruitment of ponderosa pine in these forests low. An expected benefit to opening the forests with silvicultural techniques is increased establishment of shade-intolerant ponderosa pine seedlings.

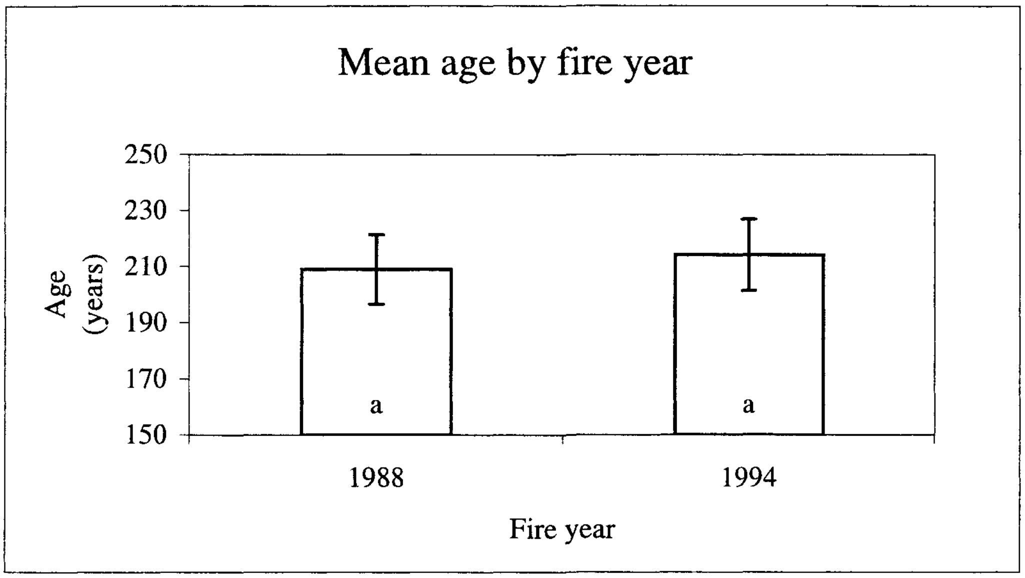

Figure 5. Mean age (years) and standard error of the sampling mean by fire year. Statistically different means are indicated with different letters (P<0.05).

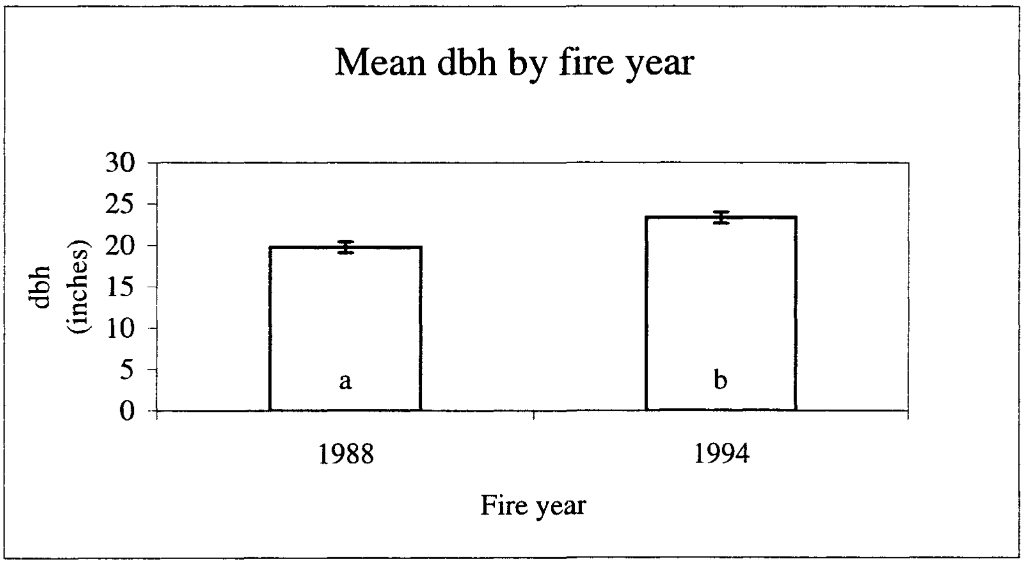

Figure 6. Mean diameter (inches) and standard error of the sampling mean by fire year. Statistically different means are indicated with different letters (P<0.05).

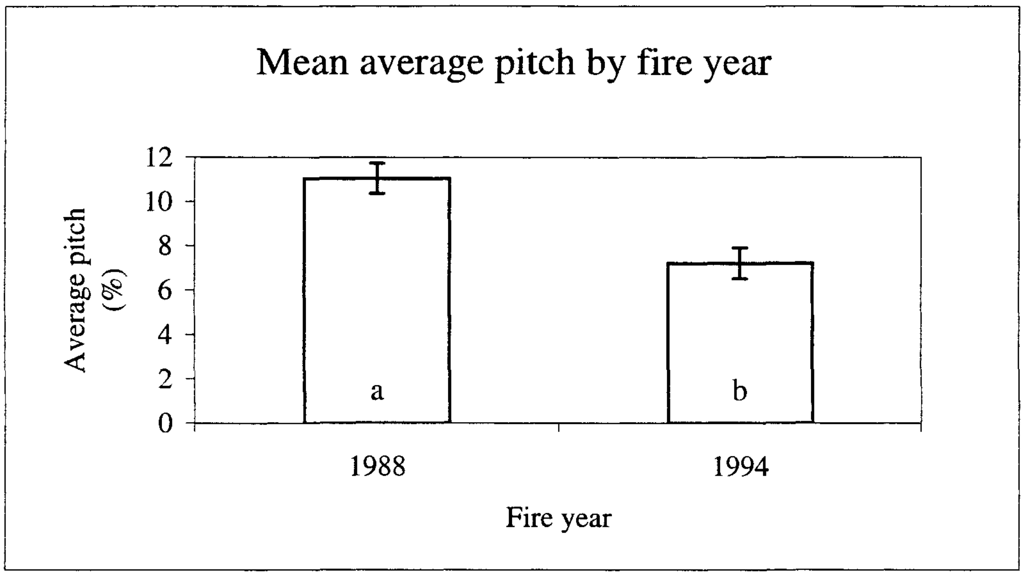

Figure 7. Mean average pitch (%) and standard error of the sampling mean by fire year. Statistically different means are indicated with different letters (P<0.05).

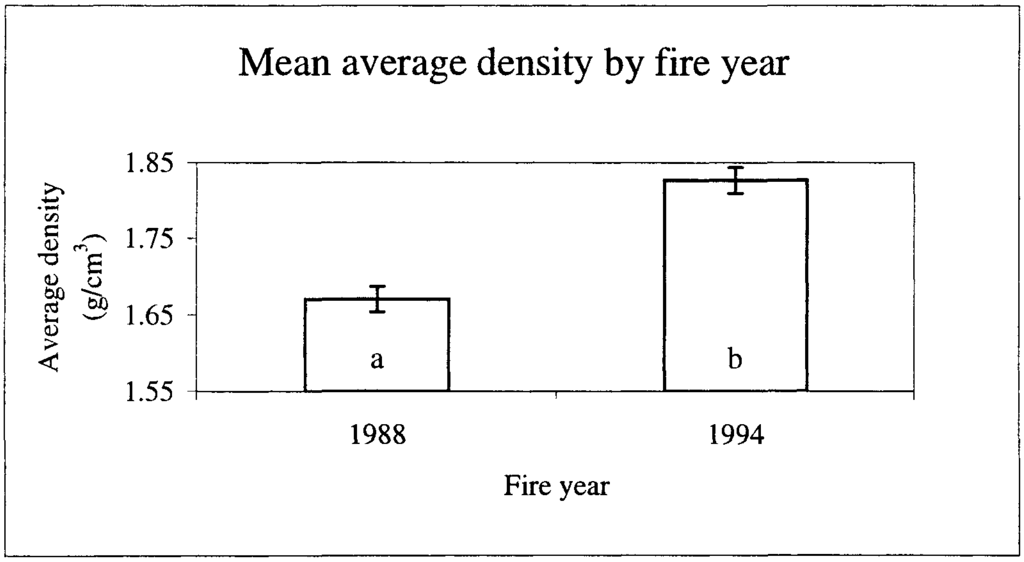

Figure 8. Mean average density (g/cm^3) and standard errors of the sampling means by site. Statistically different means are indicated with different letters (P<0.05).

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APPENDIX I

Field form used for recording data at each snag sampled

Location____ Date___________
Aspect_______ ° Slope______% H.T.________________________
Tree#________ Diameter_______" Diameter taken at __________'
Broken? __Y __N If standing, height of tree Decay class
Height of break______' __________' __________
Height age core taken at ________' Side of tree age core taken from __U __D __L __R
Pitch cores taken at ~3' on sidehills (L&R)
Approximate age of tree __________ years
Rot present?_____ How much?______" Where? OUTER INNER CENTER
Fire scars visible?____ #_____ Where on tree (U, D, L, R)?_________
Comments____
____
____
____
____

GPS File: Time: # Points:

Density cores:
Azimuth
____
____
____

APPENDIX II

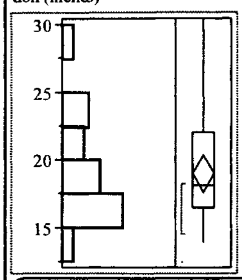
Lab form used for chemical analysis measurements

DATE:				NOTES			SAMPLE	SAMPLE	SAMPLE
STANDARDS	TIME						FLASK	FLASK	FLASK
WEIGHTS							THIMBLE	THIMBLE	THIMBLE
10 MG							WEIGHT1	WEIGHT1	WEIGHT1
20 MG									
50 MG							WEIGHT2	WEIGHT2	WEIGHT2
200 MG									
500 MG							WEIGHT3	WEIGHT3	WEIGHT3
1 G									
2 G							SAMPLE WT.	SAMPLE WT.	SAMPLE WT.
5 G									
10 G									
20 G									
BEFORE & AFTER DRYING 24 HRS.: (@50C & COOLING IN DESICCATOR FOR 1 HR.)		THIMBLE/JAR	WEIGHT1	WEIGHT2	WEIGHT3	THIMBLE/JAR	WEIGHT1	WEIGHT2	WEIGHT3
BEFORE & AFTER DRYING 1 HR.: (@ 105C & COOLING IN DESSICATOR FOR 30 MINUTES)		BEAKER	WEIGHT1	WEIGHT2	WEIGHT3	BEAKER	WEIGHT1	WEIGHT2	WEIGHT3

Appendix III

Distribution data for diameter, age, average pitch, and average density for Petty Creek 1.

dbh (inches)



Quantiles

maximum	100.0%	28.500
	99.5%	28.500
	97.5%	28.500
	90.0%	22.980
quartile	75.0%	22.100
median	50.0%	18.200
quartile	25.0%	16.500
	10.0%	15.040
	2.5%	14.000
	0.5%	14.000
minimum	0.0%	14.000

Moments

Mean	19.04194
Std Dev	3.67721
Std Error Mean	0.66045
Upper 95% Mean	20.39074
Lower 95% Mean	17.69313
N	31.00000
Sum Weights	31.00000
Sum	590.30000
Variance	13.52185
Skewness	0.87378
Kurtosis	0.36043
CV	19.31110

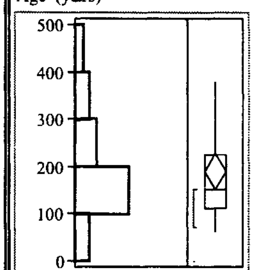
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.918730	0.0248

Not normal

Age (years)



Quantiles

maximum	100.0%	479.00
	99.5%	479.00
	97.5%	479.00
	90.0%	331.80
quartile	75.0%	227.00
median	50.0%	152.00
quartile	25.0%	113.00
	10.0%	90.60
	2.5%	73.00
	0.5%	73.00
minimum	0.0%	73.00

Moments

Mean	189.7419
Std Dev	102.9100
Std Error Mean	18.4832
Upper 95% Mean	227.4894
Lower 95% Mean	151.9945
N	31.0000
Sum Weights	31.0000
Sum	5882.0000
Variance	10590.465
Skewness	1.1944
Kurtosis	0.9795
CV	54.2368

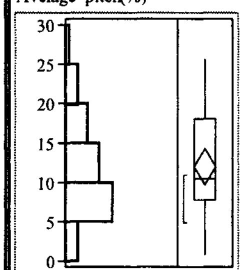
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.879560	0.0021

Not normal

Average pitch (%)



Quantiles

maximum	100.0%	25.670
	99.5%	25.670
	97.5%	25.670
	90.0%	21.351
quartile	75.0%	18.076
median	50.0%	10.509
quartile	25.0%	7.820
	10.0%	5.043
	2.5%	0.762
	0.5%	0.762
minimum	0.0%	0.762

Moments

Mean	12.05360
Std Dev	6.21800
Std Error Mean	1.11678
Upper 95% Mean	14.33436
Lower 95% Mean	9.77283
N	31.00000
Sum Weights	31.00000
Sum	373.66148
Variance	38.66347
Skewness	0.48778
Kurtosis	-0.44212
CV	51.58623

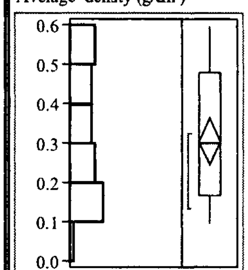
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.954843	0.2504

Normal

Average density (g/cm^3)



Quantiles

maximum	100.0%	0.59764
	99.5%	0.59764
	97.5%	0.59764
	90.0%	0.53549
quartile	75.0%	0.48071
median	50.0%	0.30006
quartile	25.0%	0.16846
	10.0%	0.11540
	2.5%	0.09514
	0.5%	0.09514
minimum	0.0%	0.09514

Moments

Mean	0.30591
Std Dev	0.15858
Std Error Mean	0.02848
Upper 95% Mean	0.36407
Lower 95% Mean	0.24774
N	31.00000
Sum Weights	31.00000
Sum	9.48311
Variance	0.02515
Skewness	0.36276
Kurtosis	-1.30481
CV	51.84001

Test for Normality

Shapiro-Wilk W Test

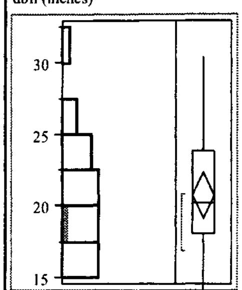
W	Prob<W
0.906556	0.0113

Not normal

Appendix III (continued)

Distribution data for diameter, age, average pitch, and average density for Petty Creek 2.

dbh (inches)



Quantiles

maximum	100.0%	30.300
	99.5%	30.300
	97.5%	30.300
	90.0%	25.280
quartile	75.0%	23.900
median	50.0%	20.300
quartile	25.0%	18.150
	10.0%	15.990
	2.5%	15.000
	0.5%	15.000
minimum	0.0%	15.000

Moments

Mean	20.78182
Std Dev	3.66679
Std Error Mean	0.78176
Upper 95% Mean	22.40757
Lower 95% Mean	19.15607
N	22.00000
Sum Weights	22.00000
Sum	457.20000
Variance	13.44537
Skewness	0.69446
Kurtosis	0.66835
CV	17.64423

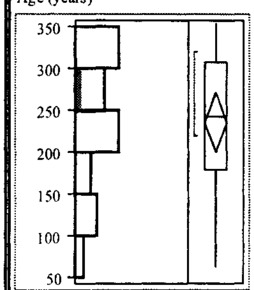
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.960018	0.4843

Normal

Age (years)



Quantiles

maximum	100.0%	348.00
	99.5%	348.00
	97.5%	348.00
	90.0%	342.00
quartile	75.0%	308.50
median	50.0%	243.50
quartile	25.0%	179.25
	10.0%	113.30
	2.5%	63.00
	0.5%	63.00
minimum	0.0%	63.00

Moments

Mean	236.0000
Std Dev	80.5647
Std Error Mean	17.1764
Upper 95% Mean	271.7201
Lower 95% Mean	200.2799
N	22.0000
Sum Weights	22.0000
Sum	5192.0000
Variance	6490.6667
Skewness	-0.4922
Kurtosis	-0.4820
CV	34.1376

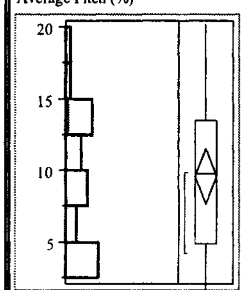
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.954826	0.3891

Normal

Average Pitch (%)



Quantiles

maximum	100.0%	18.394
	99.5%	18.394
	97.5%	18.394
	90.0%	15.799
quartile	75.0%	13.514
median	50.0%	9.751
quartile	25.0%	4.911
	10.0%	4.463
	2.5%	4.219
	0.5%	4.219
minimum	0.0%	4.219

Moments

Mean	9.60319
Std Dev	4.42250
Std Error Mean	0.94288
Upper 95% Mean	11.56400
Lower 95% Mean	7.64238
N	22.00000
Sum Weights	22.00000
Sum	211.27023
Variance	19.55849
Skewness	0.27213
Kurtosis	-1.14345
CV	46.05237

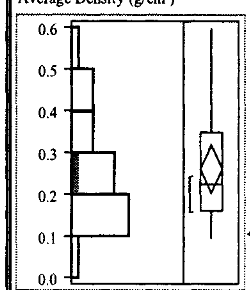
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.914088	0.0550

Normal

Average Density (g/cm³)



Quantiles

maximum	100.0%	0.52420
	99.5%	0.52420
	97.5%	0.52420
	90.0%	0.49072
quartile	75.0%	0.35062
median	50.0%	0.22436
quartile	25.0%	0.16163
	10.0%	0.12146
	2.5%	0.09899
	0.5%	0.09899
minimum	0.0%	0.09899

Moments

Mean	0.26073
Std Dev	0.12967
Std Error Mean	0.02765
Upper 95% Mean	0.31822
Lower 95% Mean	0.20323
N	22.00000
Sum Weights	22.00000
Sum	5.73599
Variance	0.01682
Skewness	0.88762
Kurtosis	-0.41220
CV	49.73587

Test for Normality

Shapiro-Wilk W Test

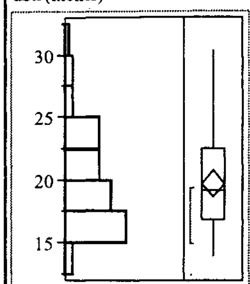
W	Prob<W
0.878862	0.0099

Not normal

Appendix III (continued)

Distribution data for diameter, age, average pitch, and average density for 1988 sites combined.

dbh (inches)



Quantiles

maximum	100.0%	30.300
	99.5%	30.300
	97.5%	29.670
	90.0%	24.800
quartile	75.0%	22.600
median	50.0%	19.200
quartile	25.0%	16.900
	10.0%	15.200
	2.5%	14.210
	0.5%	14.000
minimum	0.0%	14.000

Moments

Mean	19.76415
Std Dev	3.73899
Std Error Mean	0.51359
Upper 95% Mean	20.79474
Lower 95% Mean	18.73356
N	53.00000
Sum Weights	53.00000
Sum	1047.5
Variance	13.98004
Skewness	0.71403
Kurtosis	0.19525
CV	18.91803

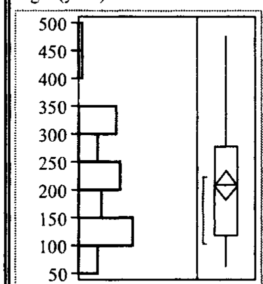
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.948478	0.0407

Not normal

Age (years)



Quantiles

maximum	100.0%	479.00
	99.5%	479.00
	97.5%	458.00
	90.0%	334.20
quartile	75.0%	279.50
median	50.0%	210.00
quartile	25.0%	119.00
	10.0%	97.40
	2.5%	66.50
	0.5%	63.00
minimum	0.0%	63.00

Moments

Mean	208.9434
Std Dev	96.2322
Std Error Mean	13.2185
Upper 95% Mean	235.4682
Lower 95% Mean	182.4186
N	53.0000
Sum Weights	53.0000
Sum	11074
Variance	9260.6313
Skewness	0.5516
Kurtosis	-0.2042
CV	46.0566

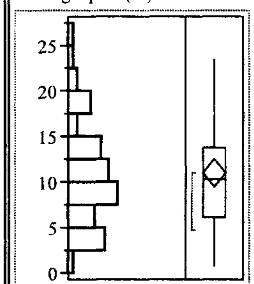
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.946444	0.0325

Not normal

Average pitch(%)



Quantiles

maximum	100.0%	25.670
	99.5%	25.670
	97.5%	24.911
	90.0%	19.065
quartile	75.0%	13.804
median	50.0%	10.354
quartile	25.0%	6.194
	10.0%	4.739
	2.5%	1.578
	0.5%	0.762
minimum	0.0%	0.762

Moments

Mean	11.03645
Std Dev	5.62942
Std Error Mean	0.77326
Upper 95% Mean	12.58810
Lower 95% Mean	9.48479
N	53.00000
Sum Weights	53.00000
Sum	584.93172
Variance	31.69034
Skewness	0.61408
Kurtosis	-0.10487
CV	51.00751

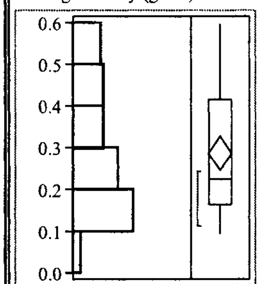
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.953422	0.0698

Normal

Average density (g/cm^3)



Quantiles

maximum	100.0%	0.59764
	99.5%	0.59764
	97.5%	0.58229
	90.0%	0.51242
quartile	75.0%	0.41641
median	50.0%	0.22723
quartile	25.0%	0.16409
	10.0%	0.12107
	2.5%	0.09649
	0.5%	0.09514
minimum	0.0%	0.09514

Moments

Mean	0.28715
Std Dev	0.14766
Std Error Mean	0.02028
Upper 95% Mean	0.32785
Lower 95% Mean	0.24645
N	53.00000
Sum Weights	53.00000
Sum	15.21909
Variance	0.02180
Skewness	0.56981
Kurtosis	-1.03434
CV	51.42347

Test for Normality

Shapiro-Wilk W Test

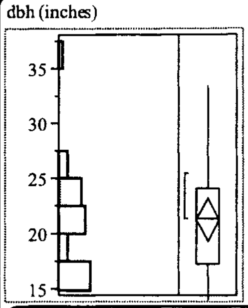
W	Prob<W
0.890151	<.0001

Not normal

Appendix III (continued)

Distribution data for diameter, age, average pitch, and average density for Niarada.

dbh (inches)



Quantiles

maximum	100.0%	35.200
	99.5%	35.200
	97.5%	35.200
	90.0%	25.420
quartile	75.0%	24.100
median	50.0%	21.400
quartile	25.0%	17.300
	10.0%	16.380
	2.5%	15.300
	0.5%	15.300
minimum	0.0%	15.300

Moments

Mean	21.26957
Std Dev	4.47492
Std Error Mean	0.93309
Upper 95% Mean	23.20465
Lower 95% Mean	19.33448
N	23.00000
Sum Weights	23.00000
Sum	489.20000
Variance	20.02494
Skewness	1.21899
Kurtosis	2.84711
CV	21.03909

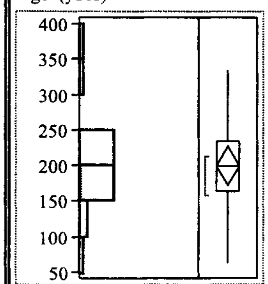
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.884026	0.0107

Not normal

Age (years)



Quantiles

maximum	100.0%	379.00
	99.5%	379.00
	97.5%	379.00
	90.0%	281.40
quartile	75.0%	234.00
median	50.0%	199.00
quartile	25.0%	164.00
	10.0%	137.40
	2.5%	66.00
	0.5%	66.00
minimum	0.0%	66.00

Moments

Mean	200.1304
Std Dev	62.3103
Std Error Mean	12.9926
Upper 95% Mean	227.0752
Lower 95% Mean	173.1857
N	23.0000
Sum Weights	23.0000
Sum	4603.0000
Variance	3882.5731
Skewness	0.7938
Kurtosis	2.5454
CV	31.1348

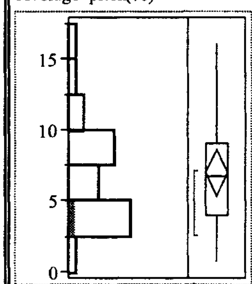
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.927598	0.0969

Normal

Average pitch(%)



Quantiles

maximum	100.0%	15.790
	99.5%	15.790
	97.5%	15.790
	90.0%	13.582
quartile	75.0%	9.050
median	50.0%	6.774
quartile	25.0%	4.060
	10.0%	2.715
	2.5%	1.998
	0.5%	1.998
minimum	0.0%	1.998

Moments

Mean	6.98985
Std Dev	3.76448
Std Error Mean	0.78495
Upper 95% Mean	8.61772
Lower 95% Mean	5.36197
N	23.00000
Sum Weights	23.00000
Sum	160.76644
Variance	14.17133
Skewness	0.81062
Kurtosis	0.11460
CV	53.85646

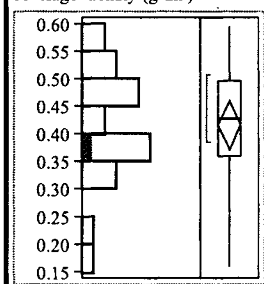
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.933831	0.1329

Normal

Average density (g/cm^3)



Quantiles

maximum	100.0%	0.57109
	99.5%	0.57109
	97.5%	0.57109
	90.0%	0.55303
quartile	75.0%	0.49563
median	50.0%	0.42745
quartile	25.0%	0.36051
	10.0%	0.25646
	2.5%	0.19442
	0.5%	0.19442
minimum	0.0%	0.19442

Moments

Mean	0.41633
Std Dev	0.10084
Std Error Mean	0.02103
Upper 95% Mean	0.45993
Lower 95% Mean	0.37272
N	23.00000
Sum Weights	23.00000
Sum	9.57557
Variance	0.01017
Skewness	-0.50189
Kurtosis	-0.18351
CV	24.22099

Test for Normality

Shapiro-Wilk W Test

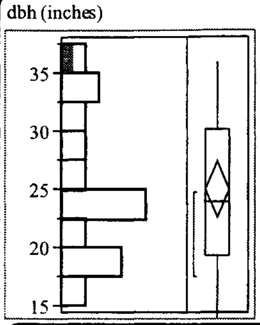
W	Prob<W
0.962113	0.5066

Normal

Appendix III (continued)

Distribution data for diameter, age, average pitch, and average density for Magruder.

dbh (inches)



Quantiles

maximum	100.0%	36.000
	99.5%	36.000
	97.5%	36.000
	90.0%	33.960
quartile	75.0%	30.200
median	50.0%	24.000
quartile	25.0%	19.400
	10.0%	17.380
	2.5%	16.500
	0.5%	16.500
minimum	0.0%	16.500

Moments

Mean	25.05926
Std Dev	5.92071
Std Error Mean	1.13944
Upper 95% Mean	27.40140
Lower 95% Mean	22.71712
N	27.00000
Sum Weights	27.00000
Sum	676.60000
Variance	35.05481
Skewness	0.34023
Kurtosis	-0.88479
CV	23.62684

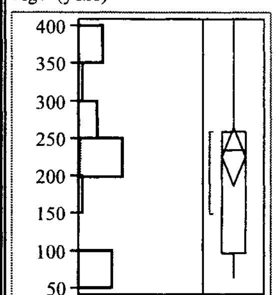
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.944930	0.1771

Normal

Age (years)



Quantiles

maximum	100.0%	378.00
	99.5%	378.00
	97.5%	378.00
	90.0%	370.80
quartile	75.0%	260.00
median	50.0%	235.00
quartile	25.0%	97.00
	10.0%	91.40
	2.5%	87.00
	0.5%	87.00
minimum	0.0%	87.00

Moments

Mean	225.9259
Std Dev	97.6501
Std Error Mean	18.7928
Upper 95% Mean	264.5547
Lower 95% Mean	187.2972
N	27.0000
Sum Weights	27.0000
Sum	6100.0000
Variance	9535.5328
Skewness	-0.0434
Kurtosis	-1.0067
CV	43.2222

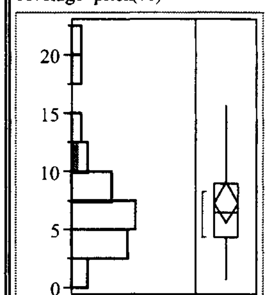
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.883727	0.0054

Not normal

Average pitch(%)



Quantiles

maximum	100.0%	20.696
	99.5%	20.696
	97.5%	20.696
	90.0%	14.482
quartile	75.0%	9.009
median	50.0%	6.490
quartile	25.0%	4.368
	10.0%	2.793
	2.5%	2.162
	0.5%	2.162
minimum	0.0%	2.162

Moments

Mean	7.38270
Std Dev	4.52777
Std Error Mean	0.87137
Upper 95% Mean	9.17381
Lower 95% Mean	5.59159
N	27.00000
Sum Weights	27.00000
Sum	199.33296
Variance	20.50072
Skewness	1.53771
Kurtosis	2.57779
CV	61.32947

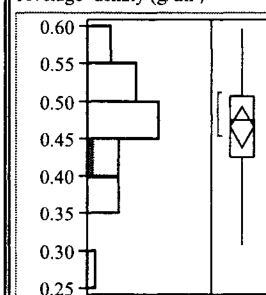
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.859890	0.0015

Not normal

Average density (g/cm^3)



Quantiles

maximum	100.0%	0.59547
	99.5%	0.59547
	97.5%	0.59547
	90.0%	0.56032
quartile	75.0%	0.50702
median	50.0%	0.47595
quartile	25.0%	0.42525
	10.0%	0.36985
	2.5%	0.29244
	0.5%	0.29244
minimum	0.0%	0.29244

Moments

Mean	0.46625
Std Dev	0.06910
Std Error Mean	0.01330
Upper 95% Mean	0.49359
Lower 95% Mean	0.43892
N	27.00000
Sum Weights	27.00000
Sum	12.58882
Variance	0.00477
Skewness	-0.47107
Kurtosis	0.33437
CV	14.82057

Test for Normality

Shapiro-Wilk W Test

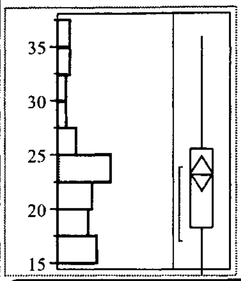
W	Prob<W
0.977215	0.8037

Normal

Appendix III (continued)

Distribution data for diameter, age, average pitch, and average density for 1994 sites combined.

dbh (inches)



Quantiles

maximum	100.0%	36.000
	99.5%	36.000
	97.5%	35.945
	90.0%	33.320
quartile	75.0%	25.675
median	50.0%	23.250
quartile	25.0%	18.300
	10.0%	17.100
	2.5%	15.465
	0.5%	15.300
minimum	0.0%	15.300

Moments

Mean	23.31600
Std Dev	5.58852
Std Error Mean	0.79034
Upper 95% Mean	24.90424
Lower 95% Mean	21.72776
N	50.00000
Sum Weights	50.00000
Sum	1165.8
Variance	31.23158
Skewness	0.71885
Kurtosis	-0.16993
CV	23.96861

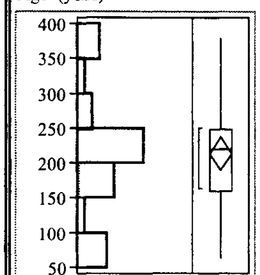
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.917464	0.0018

Not normal

Age (years)



Quantiles

maximum	100.0%	379.00
	99.5%	379.00
	97.5%	378.73
	90.0%	361.90
quartile	75.0%	249.50
median	50.0%	221.00
quartile	25.0%	160.25
	10.0%	94.20
	2.5%	71.78
	0.5%	66.00
minimum	0.0%	66.00

Moments

Mean	214.0600
Std Dev	83.4957
Std Error Mean	11.8081
Upper 95% Mean	237.7892
Lower 95% Mean	190.3308
N	50.0000
Sum Weights	50.0000
Sum	10703
Variance	6971.5269
Skewness	0.2967
Kurtosis	-0.3371
CV	39.0057

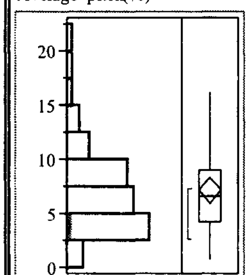
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.932591	0.0091

Not normal

Average pitch (%)



Quantiles

maximum	100.0%	20.696
	99.5%	20.696
	97.5%	20.108
	90.0%	13.344
quartile	75.0%	9.019
median	50.0%	6.632
quartile	25.0%	4.214
	10.0%	2.824
	2.5%	2.043
	0.5%	1.998
minimum	0.0%	1.998

Moments

Mean	7.20199
Std Dev	4.15688
Std Error Mean	0.58787
Upper 95% Mean	8.38336
Lower 95% Mean	6.02062
N	50.00000
Sum Weights	50.00000
Sum	360.09939
Variance	17.27969
Skewness	1.30083
Kurtosis	1.87604
CV	57.71858

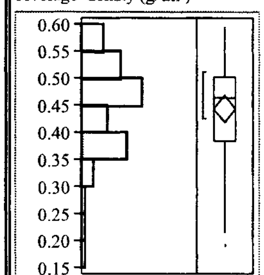
Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.893954	0.0001

Not normal

Average density (g/cm³)



Quantiles

maximum	100.0%	0.59547
	99.5%	0.59547
	97.5%	0.58876
	90.0%	0.55694
quartile	75.0%	0.50274
median	50.0%	0.46439
quartile	25.0%	0.38476
	10.0%	0.31774
	2.5%	0.20204
	0.5%	0.19442
minimum	0.0%	0.19442

Moments

Mean	0.44329
Std Dev	0.08793
Std Error Mean	0.01243
Upper 95% Mean	0.46828
Lower 95% Mean	0.41830
N	50.00000
Sum Weights	50.00000
Sum	22.16439
Variance	0.00773
Skewness	-0.74253
Kurtosis	0.50188
CV	19.83482

Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.953174	0.0801

Normal